The linear dependence of the passive reals rate on the $^{235}U$ enrichment is given in Fig. 14 as

$$R\ (passive) = 3.17 + 0.577\ E_n \quad \text{(BWR, UNCL-II)}\ ,$$

and

$$R\ (passive) = 9.73 + 1.63\ E_n \quad \text{(PWR, UNCL-II)}\ .$$

If we normalize the $R$ values by the zero enrichment value of $R_0$, we get

$$R/R_0 = 1 + 0.182\ E_n \quad \text{(BWR, UNCL-II)}\ ,$$

and

$$R/R_0 = 1 + 0.168\ E_n \quad \text{(PWR, UNCL-II)}\ ,$$

and these normalized functions give the enrichment dependence of the passive $R$ rate for any collar.

Because we have measured the passive mode calibration by removing rods and keeping the enrichment fixed at 3.19%, the passive $R$ enrichment correction factor for other enrichments $(E_n)$ is

$$\frac{\underline{Reference\ E_n\ corr.}}{General\ E_n\ corr.} = \frac{1 + 0.182\ (3.19)}{1 + 0.182\ E_n} = \frac{1.581}{(1 + 0.182\ E_n)} \quad \text{(BWR, UNCL-II)}\ .$$

## C. Passive Reals Correction

When we combine the room-background neutron correction with the enrichment correction, we get for BWR assemblies

$$R(corr.) = [R(meas.) - 0.014\ (T\text{-}45)]\ \frac{1.581}{(1 + 0.182\ E_n)}\ ,$$

and for PWR assemblies

$$R(corr.) = [R(meas.) - 0.014\ (T\text{-}120)]\ \frac{1.536}{(1 + 0.168\ E_n)}\ .$$

These two equations have room-background corrections that correspond to the UNCL (Mod-I) units. For the new UNCL-II units, the passive efficiencies are higher and the measured $R$ and $T$ rates must be reduced to use the UNCL (LANL-1) passive calibration curves shown in Fig. 15.

Table XIX lists the passive coincidence rates for all of the collar units that were calibrated with the LANL BWR and PWR fuel assemblies. The normalized ratios of

$$\frac{R(LANL\text{-}1)}{R(XX)} = r$$

are used to correct the measured reals rate, $R(meas)$, to the calibration curves given in Fig. 15, and the $r$ values given in Table XIX. The passive correction for any collar is

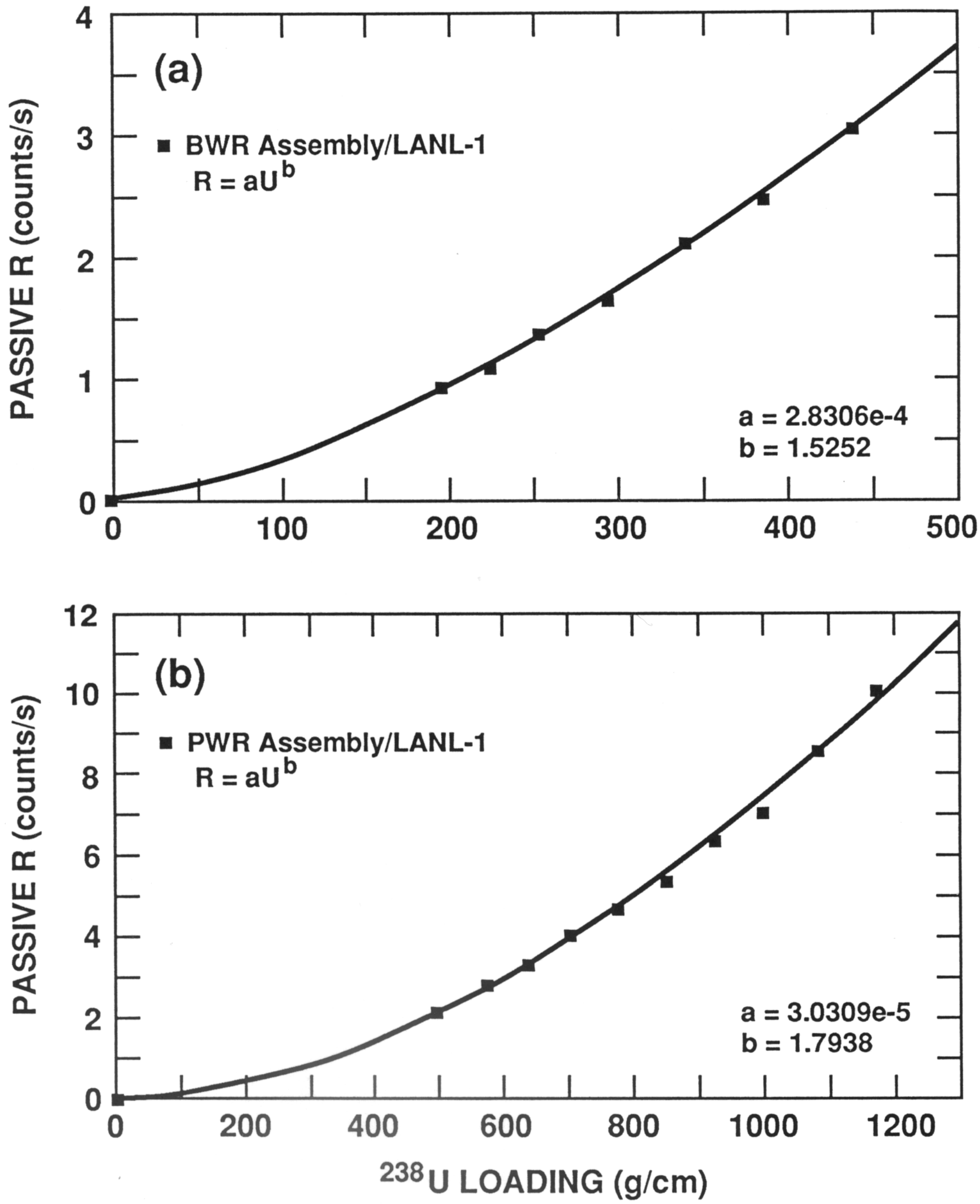


*Fig. 15. Reference passive calibration curves for quantitative measurement of $^{238}U$ g/cm. The reference data correspond to the UNCL (LANL-1).*

$$R(corr.) = [r\, R(meas.) - 0.014\, (\sqrt{r}\, T - 45)] \frac{1.581}{(1 + 0.182\, E_n)} ,$$

$$R(corr.) = [r\, R(meas.) - 0.014\, (\sqrt{r}\, T - 120)] \frac{1.536}{(1 + 0.168\, E_n)} ,$$

for BWR and PWR assemblies, respectively. For the reference case of LANL-1 and $E_n = 3.19\%$, $R(corr.) = R(meas.)$.

## D. BWR Calibration Curve (Passive)

The calibration curve for BWR assemblies is given in Fig. 15. The g $^{238}$U/cm can be obtained directly from the curve.

The data were fit by the power function

$$R(corr.) = aU^{b} ,$$

where

$$a = (2.83 \pm 0.49) \times 10^{-4} \text{, and}$$

$$b = 1.525 \pm 0.0295 .$$

The covariances are

$a$: $a$ $2.413 \times 10^{-9}$
$a$: $b$ $-1.448 \times 10^{-6}$
$b$: $b$ $8.705 \times 10^{-4}$ .

Inverting the equation gives

$$U = 212\, R^{0.656} ,$$

where $U$ is the g $^{238}$U/cm and $R$ is the corrected passive rate.

## E. PWR Calibration Curve (Passive)

The passive calibration curve for PWR assemblies is given in Fig. 15. The power function fit was

$$R\, (corr.) = aU^{b} ,$$

where

$$a = (3.03 \pm 0.10) \times 10^{-5} ,$$
$$b = 1.794 \pm 0.048 ,$$

and

$$a{:}a \;\; 1.020 \times 10^{-10}$$
$$a{:}a \; -4.887 \times 10^{-7}$$
$$b{:}b \;\; 2.343 \times 10^{-3} \; .$$

Inverting the equation gives

$$U = 330\, R^{0.557} \quad .$$

**F. Enrichment Calculation**

The $^{235}U$ enrichment is calculated from

$$^{235}U(enrichment) = \frac{g\ ^{235}U/cm}{g\ ^{235}U/cm + g\ ^{238}U/cm} \quad .$$

This value is used only to check the operator's declaration of enrichment because the passive measurement of the g $^{238}U$/cm has a relatively large uncertainty.

**G. Moderator Substitution**

An additional benefit of the passive measurement is that it prevents the undetected substitution of moderator rods for $UO_2$ rods. Such a substitution would cause a drop in the passive coincidence rate.

## SUMMARY

The calibration curves and cross-reference tables are presented for BWR and PWR fuel assemblies, both with and without Cd liners. The curves are presented for the reference UNCL-II units and reference PWR and BWR fuel assemblies. For field conditions using different UNCL units for a wide variety of fuel assemblies, signal conditioning factors $(k_0 \bullet k_1 \bullet k_2 \bullet k_3 \bullet k_4 \bullet k_5 = k)$ are presented to correct the measured response to the calibration conditions.

Cd-ratio measurements can be performed to make the measurement independent of the declared poison rod loading in the fuel assembly.

For future applications of the UNCL to verify the $^{238}U$ content as well as the $^{235}U$ content, we have presented the passive mode calibration functions and cross-reference parameters. The active mode ($^{235}U$) calibration can be used without the quantitative $^{238}U$ calibration that is presented in Section XI.

Appendix A presents data showing the position sensitivity for the substitution or removal of fuel rods.

## REFERENCES


1. H. O. Menlove, "Description and Performance Characteristics for the Neutron Coincidence Collar for the Verification of Reactor Fuel Assemblies," Los Alamos National Laboratory report LA-8939-MS (ISPO-142) (August 1981).